Journal of the American College of Cardiology
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Published by Elsevier Science Inc.

Vol. 34, No. 7, 1999
ISSN 0735-1097/99/$20.00
PII S0735-1097(99)00466-0

The Significance of Persistent ST Elevation Versus Early Resolution of ST Segment Elevation After Primary PTCA

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OBJECTIVES To determine the prevalence and clinical significance of early ST segment elevation resolution after primary percutaneous transluminal coronary angioplasty (PTCA) for acute myocardial infarction (AMI).

BACKGROUND Despite angiographically successful restoration of coronary flow early during AMI, adequate myocardial reperfusion might not occur in a substantial portion of the jeopardized myocardium due to microvascular damage. This phenomenon comprises the potentially beneficial effect of early recanalization of the infarct related artery (IRA).

METHODS Included in the study were 117 consecutive patients who underwent angiographically successful [Thrombolysis in Myocardial Infarction (TIMI III)] primary PTCA. The patients were classified based on the presence or absence of reduction ≥50% in ST segment elevation in an ECG performed immediately upon return to the intensive cardiac care unit after the PTCA in comparison with ECG before the intervention.

RESULTS Eighty-nine patients (76%) had early ST segment elevation resolution (Group A) and 28 patients (24%) did not (Group B). Group A and B had similar clinical and hemodynamic features before referring to primary PTCA, as well as similar angiographic results. Despite this, ST segment elevation resolution was associated with better predischarge left ventricular ejection fraction (LVEF) (44.7 ± 8.0 vs. 38.2 ± 8.5, $p < 0.01$). Group B patients, as compared with those of Group A, had a higher incidence of in-hospital mortality (11% vs. 2%, $p = 0.088$), congestive heart failure (CHF) [28% vs. 19%, odds ratio (OR) = 4, 95% confidence interval (CI) 1 to 15, $p = 0.04$], higher long-term mortality (OR = 7.3, 95% CI 1.9 to 28, $p = 0.004$ with Cox proportional hazard regression analysis) and long-term CHF rate (OR = 6.5, 95% CI 1.3 to 33, $p = 0.016$ with logistic regression).

CONCLUSIONS Absence of early ST segment elevation resolution after angiographically successful primary PTCA identifies patients who are less likely to benefit from the early restoration of flow in the IRA, probably because of microvascular damage and subsequently less myocardial salvage. (J Am Coll Cardiol 1999;34:1932–8) © 1999 by the American College of Cardiology

In acute myocardial infarction (AMI) patients who are treated with thrombolytic therapy, early resolution of ST segment elevation is associated with early restoration of coronary blood flow (1–4) and, consequently, smaller infarct size (1,4–6) and better clinical outcome (5–6). When early reperfusion is attempted by primary percutaneous transluminal coronary angioplasty (PTCA), the flow pattern in the infarct related artery (IRA) is routinely recorded at the end of the intervention. However, in previous myocardial contrast echo (MCE) (7–13), scintographic (14–15) and MRI (16) studies, it was shown that even early restoration of the Thrombolysis in Myocardial Infarction (TIMI) grade III flow in the IRA (either by thrombolysis or primary PTCA) was not always associated with myocardial reperfusion due to microvascular damage. This pathologic process, which was termed the "no-reflow" phenomenon, significantly comprises the beneficial effect of early recanalization of the IRA during AMI (7–10,12,16–18). We postulated that early changes in the ST segment elevation, which reflect the electrical changes in the jeopardized myocardium itself, might provide important information regarding myocardial reperfusion after primary PTCA. The objective of this study was to determine the prevalence and clinical significance of

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Manuscript received December 31, 1998; revised manuscript received June 15, 1999, accepted September 1, 1999.

Abbreviations and Acronyms

AMI = acute myocardial infarction
CAD = coronary artery disease
CHF = congestive heart failure
CK = creatine kinase
IABP = intra-aortic balloon pulsation
ICCU = intensive cardiac care unit
IRA = infarct related artery
LV = left ventricle
LVEF = left ventricular ejection fraction
MCE = myocardial contrast echo
PTCA = percutaneous transluminal coronary angioplasty
TIMI = Thrombolysis in Myocardial Infarction

early ST segment elevation resolution after angiographically successful primary PTCA.

METHODS

Study population. The study population consisted of consecutive AMI patients who underwent primary PTCA and complied with the following criteria: 1) ST segment elevation ≥2 mm in at least two contiguous leads on the admission ECG, 2) absence of significant ST segment elevation resolution before the PTCA, 3) achievement of TIMI grade III flow with <50% stenosis in the IRA. The diagnosis of AMI was made on the basis of ischemic chest pain lasting at least 30 min and ST segment elevation in at least two contiguous leads. Acute myocardial infarction patients who were eligible for reperfusion therapy were treated with PTCA whenever one of the following conditions existed: 1) contraindication to thrombolytic therapy, 2) Killip ≥2 on admission, 3) hemodynamic instability (regardless of infarct site), 4) any extensive anterior wall MI, if PTCA was feasible within 1 h of admission. Otherwise the patients were treated with thrombolytic therapy. Between 1994 and 1996, 155 patients with ST segment elevation AMI were referred for primary PTCA based on the above mentioned criteria. In nine patients the ST segment elevation resolved by 50% or more in sequential ECG's before the PTCA. In 11 patients the flow in IRA could be restored but TIMI III was not achieved, and four other patients were referred for emergent coronary artery bypass graft for diffuse and severe coronary artery disease (CAD). In 14 patients ECG was not repeated immediately after the PTCA. The remaining 117 patients were enrolled in this study.

ECG. The sum of ST segment elevation in the three contiguous leads with the highest ST segment elevation (ΣST) was calculated in two ECG's: the latest ECG which was performed (≤30 min) before the PTCA and the first ECG after the intervention on return to the intensive cardiac care unit (ICCU). The ST segment elevation was measured 0.08 s after the J point by two investigators who were unaware of the clinical and angiographic findings. A reduction of at least 50% in the ΣST segment elevation between the pre- and post-PTCA ECG's was considered as significant ST segment elevation resolution.

Coronary angiography. Coronary angiography and primary PTCA were performed in a routine manner. The first balloon inflation was performed on the average 3.3 ± 3 h (median 3.25 h [2.3, 4.5]) after the onset of chest pain. Angioplasty was repeated to restore normal (TIMI III) flow in the IRA and reduce the degree of residual stenosis to less than 30%. The final angiogram was evaluated for the residual stenosis in the IRA by the quantitative coronary angiography technique. When this angiographic goal could not be accomplished by PTCA or was complicated by dissection or reocclusion, stents were employed. The flow in the IRA on the initial diagnostic angiogram and in that obtained after completion of the intervention were classified using the TIMI criteria. All angiograms were interpreted by two angiographers who were blinded to changes in ST segment elevation and to the clinical outcomes. All patients were treated with aspirin (250 mg/day) and after stent placement were treated with ticlopidine (500 mg/day) for four weeks.

Echocardiographic technique. A commercially available echocardiographic system (Hewlett-Packard Sonos 1500; Hewlett-Packard Co., Andover, Massachusetts) employing a 2.5 MHz transducer was used in this study. Patients received a complete standard Doppler-echocardiographic examination prior to hospital discharge. Left ventricular ejection fraction (LVEF) was visually estimated (19) by an echocardiographer unaware of the early changes in ST segment elevation and the angiographic results.

Clinical follow-up. All patients were prospectively followed during the hospital stay for the occurrence of the following adverse events: congestive heart failure (CHF), reinfarction, recurrent angina and death. Congestive heart failure was defined by the presence of symptoms or signs of pulmonary congestion or the need for diuretic treatment in order to control such symptoms. Reinfarction was diagnosed based on the recurrence of persistent ischemic chest pain followed by at least two-fold reelevation of creatine kinase (CK) from the last measured value. Any recurrent chest pain which was accompanied by ST-T segment changes on the ECG was considered as recurrent angina if reinfarction was ruled out. The combined end point of mortality or CHF was considered a priori. For all patients' mortality, data were obtained from the Israeli population registry at the Ministry of the Interior. Fifty-five of the patients were followed up periodically in our out-patient clinic. The patients were examined at least once every 6 months or more frequently when clinically required. For those patients, the long-term occurrence of CHF, recurrent angina and reinfarction were recorded, using the same definitions used for events during hospital stay.

Statistical methods. In the comparison of patients with and without early ST segment elevation resolution, the differences in parametric variables were assessed by the Pearson chi-square test when the minimal expected number of observations was more than five and Fisher exact test was used otherwise. Continuous variables are presented as mean ± standard deviation and median (Q1, Q3) where Q1 and Q3 are the first and the third quartiles respectively. For the comparison of continuous variables, a *t* test was used when the distribution was normal and otherwise the Wilcoxon rank test was used. Multivariate analysis of binary outcomes independent of their time occurrence during the follow-up period (in-hospital CHF, long-term CHF, one-year mortality) was performed by logistic regression, and Cox proportional hazard regression was used in multivariate analysis of long-term mortality where the occurrence time was considered. The multivariate analysis was performed in two stages. In the initial step, we performed a forward stepwise regression of all variables which had a p value <0.25 in the univariant analysis or of known clinical importance (age, gender, risk factors for CAD, previous MI, MI location, time elapsed from symptom onset to PTCA, Killip class, ΣST segment elevation, pre-MI treatments, use of catecholamines before PTCA and intra-aortic balloon pulsation (IABP), multivessel CAD on angiography, stent placement). In the second step, we achieved the final best model by performing backward stepwise regression of the variables selected in the initial step.

RESULTS

The first ECG after the primary PTCA was performed immediately upon the return of the patients to the ICCU, on the average 1.44 ± 0.62 h (median 1.3 h [1, 1.7]) after the first balloon inflation. Figure 1 describes the spectrum of ST segment elevation resolution in the entire study population. Based on this ECG, 89 patients (76%) had early resolution of ST segment elevation (group A) and 28 patients (24%) did not (group B).

Baseline characteristics. The patients in group A, as compared with those in group B, had a somewhat greater incidence of hypertension (37% vs. 18%, p = 0.096) and previous MI (36% vs. 18%, p = 0.12), and lesser prevalence of diabetes mellitus (19% vs. 32%, p = 0.24). Otherwise the patients in both groups were similar with respect to age, gender, other risk factors for CAD and cardiovascular history (Table 1).

More patients in group A as compared with group B were treated with beta-adrenergic blocking agents (26% vs. 0%, p = 0.0064) and aspirin (42% vs. 14%, p = 0.015) prior to the qualifying AMI. There were no differences in the prevalence of patients who were on calcium channel blockers (19% vs. 11%, p = 0.4) or nitrates (21% vs. 7%, p = 0.15). However, in multivariate analysis, which controlled for previous cardiovascular history and risk factors for CAD, the prior medical treatment was not a significant predictor of ST segment elevation resolution.

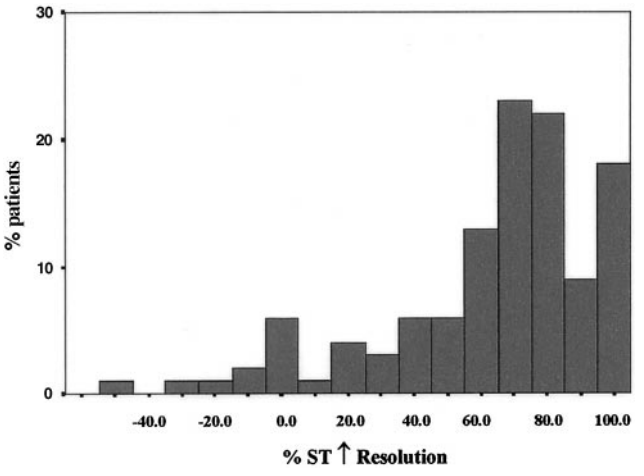

Figure 1. The distribution of the entire study population according to the extent of ST segment elevation resolution immediately after the primary PTCA, expressed as percentage decrease of the ΣST segment elevation before the procedure. In five patients there was further ST segment elevation reelevation after the procedure which is presented as negative numbers.

Clinical characteristics before the performance of primary PTCA. The patients in group A and group B were also comparable with respect to clinical and hemodynamic characteristics on admission and prior to the performance of primary PTCA (Table 2). The two groups were similar with respect to distribution of infarct site (anterior vs. inferior), heart rate, blood pressure and Killip class on admission, as well as with regard to the need for mechanical ventilation, catecholamine treatment and IABP before or during the intervention. Group A patients as compared with group B patients had, although not statistically significant, a shorter time interval from onset of symptoms to ICCU admission (1.2 ± 7.5 h vs. 2.96 ± 3.2 h, median 1.7 h [1.2, 2.8] vs. 2 h (1, 3) p = 0.25) and, as a result, shorter interval to primary PTCA (3.56 ± 2.0 h vs. 4.46 ± 3.4 h, median 3 h [2.3, 4.5] vs. 4 h (2.5, 4.3) p = 0.22). The time interval from primary PTCA (first balloon inflation) to the recording of the first ECG after the intervention was similar in group A and Group B (1.48 ± 0.62 h vs. 1.29 ± 0.99 h, median 1.3 h [1, 1.9] vs. 1.3 h (0.8, 1.7) p = 0.24).

Angiographic characteristics. On the initial diagnostic angiogram TIMI flow ≥2 was demonstrated in the IRA in 25 (25%) and 5 (18%) patients of groups A and B, respectively (p = 0.4). The patients in both groups also had similar prevalence of multivessel CAD (52% vs. 43% in group A and group B, respectively, p = ns), similar rate of dissection as a complication of the PTCA (8% vs. 9%, p = 0.56) and, in a similar number, a stent was placed in the IRA (22% vs. 19%, p = 0.94).

Table 1. Baseline Characteristics

	Early ST Segment Elevation Resolution N = 89 (Group A)	No Early ST Segment Elevation Resolution N = 28 (Group B)	p Value
Age	57.5 ± 14.5	58.7 ± 12	0.7
Gender: Male	65 (73%)	21 (75%)	1.0
Risk Factors			
Smoking	41 (46%)	13 (46%)	1.0
Hypertension	33 (37%)	5 (18%)	0.096
Diabetes mellitus	17 (19%)	9 (32%)	0.24
Hypercholesterolemia	35 (39%)	6 (21%)	0.13
Family history of CAD	34 (38%)	9 (32%)	0.72
Cardiovascular History			
Previous MI	32 (36%)	5 (18%)	0.12
Previous angina	43 (48%)	10 (37%)	0.42
Previous CVA	6 (7%)	3 (11%)	0.44

Left ventricular function evaluation. Pre-hospital discharge echocardiographic study technically suitable for estimating LVEF was available in 80 survivors of group A (92%) and in 23 survivors of group B (92%). Early ST segment elevation resolution was associated with higher predischarge LVEF (44.7 ± 8.0% vs. 38.2 ± 8.5% median 44.5% [38, 50] vs. 39% [30, 46] for group A and group B, respectively $p < 0.01$). In agreement, group A as compared with group B patients also tended to have lower peak CK value (1072 ± 1090 IU vs. 1209 ± 838 IU median 681 IU [387, 1400] vs. 881.5 IU [640, 1490] $p = 0.11$). Among the 55 patients who were followed in our outpatient clinic, 32 patients (58%) had repeated echocardiographic examination within the first six months after discharge (23 belonged to group A and 9 to group B). While the average change in LVEF in group A was 3.3 ± 7.6, in group B it was only 0.2 ± 0.12 ($p = 0.18$).

In-hospital clinical outcome (Fig. 2). Early ST segment elevation resolution was associated in univariate analysis with a trend towards lower prevalence of CHF (19% vs. 28% in group A and B, respectively, $p = 0.11$) and lower mortality (2% vs. 11%, $p = 0.088$). There were no differences in the prevalence of recurrent angina (17% vs. 19%, $p = 1.0$) and none of the patients in either group had reinfarction. In multivariate analysis with adjustment for age, gender, risk factors for CAD, previous MI, medical therapy prior to the AMI and before the PTCA, MI location, Killip class, IABP placement and multivessel CAD on angiography, the absence of early ST segment elevation resolution was a significant and independent predictor of a higher rate of CHF (OR = 4, 95% CI 1 to 15, $p = 0.04$) and of the combined end point CHF or mortality (OR = 3.5, 95% CI 1 to 12, $p < 0.05$). In the best final model, in addition to early ST segment elevation resolution, only treatment with catecholamines before the PTCA, time to PTCA and IABP placement were independent correlates of CHF. Age, time to PTCA and need for mechanical ventilation were the independent predictors for mortality and CHF in addition to ST segment elevation resolution. Because of the small number of patients who died during hospitalization, we did not perform multivariate analysis for mortality. Although the prevalence of early ST segment

Table 2. Clinical and Hemodynamic Characteristics Prior to the Performance of Primary PTCA

	Early ST Segment Elevation Resolution N = 89 (Group A)	No Early ST Segment Elevation Resolution N = 28 (Group B)	p Value
AMI location:			
Anterior	55 (62%)	18 (64%)	0.98
Admission heart rate	77 ± 21	79 ± 20	0.65
Admission blood pressure	125 ± 32	130 ± 34	0.54
Killip I	59 (66%)	17 (61%)	0.8
Killip IV	16 (18%)	5 (18%)	1.0
Mean Killip class	1.78 ± 1.2	1.82 ± 1.2	0.86
IABP	40 (45%)	10 (36%)	0.52
Mechanical ventilation	18 (20.5%)	5 (18%)	0.98
Catecholamine administration	13 (15%)	5 (18%)	0.76

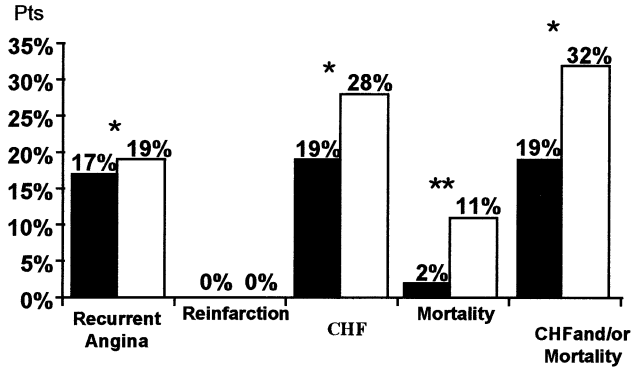

Figure 2. Prevalence of in-hospital adverse events in patients with (group A) and without (group B) early ST segment elevation resolution. *p = NS; **p = 0.088. **Solid bars** = Group A; **open bars** = Group B.

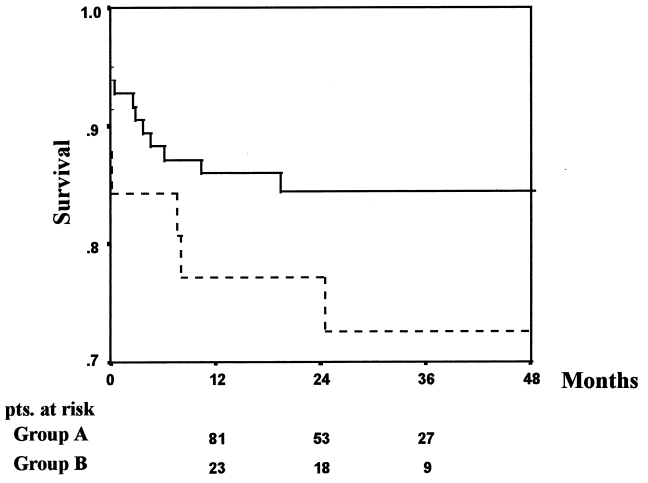

Figure 4. Kaplan-Meier curves for long-term survival according to the presence **(solid line)** or absence **(dotted line)** of early ST segment elevation resolution (p = 0.12 in log-rank test). **Solid line** = Group A; **dotted line** = Group B.

elevation resolution was not influenced by the Killip class on admission (entire study population: 76%, Killip II–IV: 73%, Killip III–IV: 77% and Killip IV: 76%) as shown in Figure 3, the differences between groups A and B increased with the severity of the initial clinical decompensation and was reflected by the Killip classification.

Long-term clinical outcome. Mortality data was available for 116 (99%) patients. (One patient was a visitor while he experienced the qualifying AMI and was not available for follow-up.) The average follow-up period was 30 ± 10 (12.4 to 48) months and it did not differ between patients with (group A) and those without early ST segment elevation resolution (group B). As demonstrated by the Kaplan-Meier curves for long-term survival in Figure 4, the absolute difference of 9% in mortality which was noted between group A and group B patients at the end of the hospital stay persisted throughout the entire post-discharge follow-up period. During the first year, eight (9%) patients died in group A and five (18%) in group B, and during the entire follow-up period, the mortality rates were 12% and 21%, respectively (p = 0.12 in log-rank test). When the relation between early ST segment elevation resolution and long-term (30 ± 10 months) mortality was studied in a multivariate analysis, absence of early ST segment elevation resolution was significantly associated with higher long-term mortality (OR = 7.3, 95% CI 2 to 29, p = 0.0004 in Cox proportional hazard regression analysis) and with one year mortality (OR = 14, 95% CI 2 to 99, p = 0.0005 in logistic regression analysis). In the final model, besides early ST segment elevation resolution, age, pretreatment with aspirin and treatment with catecholamines before the PTCA were independent significant correlates of long-term survival. Among the 25 patients who were presented with cardiogenic shock, the long-term survival was 75% in those who had early ST segment elevation resolution as compared with only 20% in those who did not have early ST segment elevation resolution, ($p < 0.05$) despite early angiographically successful primary PTCA in all patients. The 55 patients who were routinely followed in our outpatient clinic were comparable with the entire study population with respect to epidemiologic, clinical and hemodynamic baseline characteristics and had similar angiographic and in-hospital clinical results (data not presented). Absence of early ST segment elevation resolution which occurred in 25% of those patients was an independent predictor of a higher rate of CHF during the follow-up period (50% vs. 27%, OR = 6.5, 95% CI 1.3 to 33, p = 0.016). The only two other predictors of long-term CHF were the initial ΣST segment elevation (p = 0.012) and angiotensin converting enzyme (ACE) inhibitors administration (p = 0.046). There were no differences in the prevalence of reinfarction or reappearance of angina.

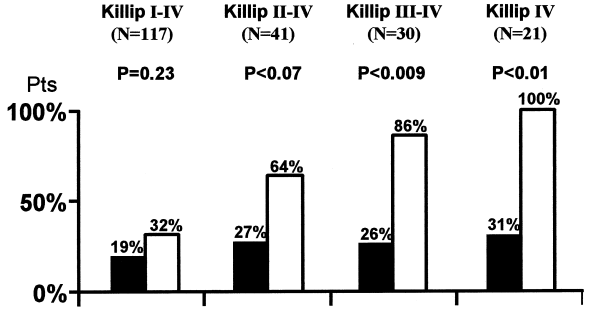

Figure 3. Comparison of in-hospital mortality and CHF in patients with (group A) and without (group B) early ST segment elevation resolution according to Killip classification on admission. **Solid bars** = Group A; **open bars** = Group B.

Discussion. Primary PTCA was shown to be an effective reperfusion strategy, which confers early restoration of adequate coronary flow in more than 75% of the patients (20,21). However, previous myocardial contrast echo

(MCE) studies demonstrated that, despite early restoration of TIMI grade III flow in the IRA, myocardial reperfusion may fail to occur in a substantial portion of the jeopardized myocardium (7–13). This phenomenon was originally demonstrated in animal models of ischemia and reperfusion and was termed the "no-reflow" phenomenon (22,23). This phenomenon is associated with extensive microvascular damage (22–24) and with larger infarction (12,16,17), poorer left ventricle (LV) functional recovery (7–10,12,15,17), LV remodeling (12–16) and increased frequency of CHF, malignant arrhythmias and myocardial rupture (12,16). Thus, after primary PTCA, even if optimal angiographic results are achieved, complete evaluation of reperfusion success necessitate assessment of myocardial reperfusion.

In this study we found that early ST segment elevation resolution after angiographically successful primary PTCA was associated with smaller myocardial damage and predicted better myocardial salvage and clinical outcome. The more complete reperfusion in those with early ST segment elevation resolution was also suggested by the different impact of the Killip classification prior to the intervention on the final outcome despite the similar angiographic picture. As demonstrated by Figure 3, in patients without early ST segment elevation resolution, the clinical outcome deteriorated significantly with increase of Killip class, whereas in those patients with early ST segment elevation resolution, this trend was substantially attenuated.

Previous studies. Recently, Van't Hof et al. (25) demonstrated in a larger cohort, significant correlation between the extent of ST segment elevation resolution within 1 h of primary PTCA and reduction of the enzymatic infarct size, improved LVEF and mortality. However, some differences existed between the two studies: 1) due to differences in the criteria used in triaging AMI patients for primary PTCA, the patients included in this study represent a group of higher risk patients who were more likely to have anterior AMI (62% vs. 44%), previous MI (32% vs. 19%) and diabetes mellitus (22% vs. 7%) and 18% of whom presented with cardiogenic shock. This enabled us to show that the prognostic value of early ST segment elevation resolution is enhanced with the severity of the clinical status. 2) Van't Hof et al. (25) divided their patients into three groups according to the extent of ST segment elevation resolution: patients with complete resolution, partial resolution (at least 30% resolution) and no resolution. We demonstrated basically similar findings with a more simplified model of patients differentiated into only two groups based on the presence or absence of ST segment elevation resolution of at least 50%.

In agreement with these findings, Kabayashi et al. (26) showed that immediate ST segment elevation resolution after angiographically successful primary PTCA, as compared with the absence of immediate change in ST segment elevation or further ST reelevation, predicted better LVEF improvement and higher LVEF in the chronic phase of the AMI. Similarly we recently showed that, in patients with early peak CK after thrombolytic therapy as a marker of early recanalization, rapid ST segment elevation resolution identifies patients with better myocardial salvage (27). In this study we suggested microvascular damage and the "no-reflow" phenomenon as an explanation for the less beneficial effect of angiographic reperfusion in patients without early ST segment elevation resolution although this mechanism has not been proven directly. Yet, previous MCE studies showed that when the "no-reflow" phenomenon occurs as a complication of coronary intervention, either during or not during AMI, it is accompanied by ST segment elevation on the ECG (24,28,29).

Study limitations. We call for caution in interpreting the results of our study due to the relatively small sample size. Furthermore, several more specific, potential limitations of this study should be considered. Although long-term mortality data was available for 97% of the patients, information regarding long-term CHF and recurrent ischemic events was available only in 55 patients who were periodically followed-up in our outpatient clinic.

However, a similar percentage of group A and group B patients were followed-up so that patients with and without ST segment elevation resolution were presented in identical proportions in the entire population and among those who were followed-up. Moreover, the 55 patients who were routinely followed-up in our out-patient clinic had similar baseline and angiographic characteristics, similar in-hospital course and even similar long-term survival rates as compared with the entire study population. This further decreased the likelihood of severe selection bias.

An additional potential limitation is inherent in the study design, to judge the presence of ST segment elevation resolution based on the first ECG that was performed upon return of the patients from the catheterization laboratory to the ICCU and not after a predetermined constant time period as is the custom after thrombolytic therapy. As a consequence the time that elapsed between the first balloon inflation and the performance of the ECG differed between the patients. Probably more accurate information might have been provided by continuous ECG recording. Yet, our study design makes the results of this study directly applicable to the routine clinical settings. Moreover, the average time elapsed from the PTCA to the performance of the post-PTCA ECG did not differ significantly between the two study groups and therefore did not bias the results.

Clinical implication. In aggregate with previous studies, our findings suggest that, after angiographically successful primary PTCA, early ST segment monitoring provides important information regarding the level of myocardial reperfusion. We suggest that the use of a simple electrocardiographic marker, ST segment elevation resolution of at least 50% in the early stages after primary PTCA in combination with the angiographic results, provides more

comprehensive evaluation of the quality of reperfusion and improves the ability to predict the outcome of patients post-primary PTCA. Such information may be important if new adjunctive strategies will be available for treatment of microvascular damage and improvement of myocardial reperfusion.

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